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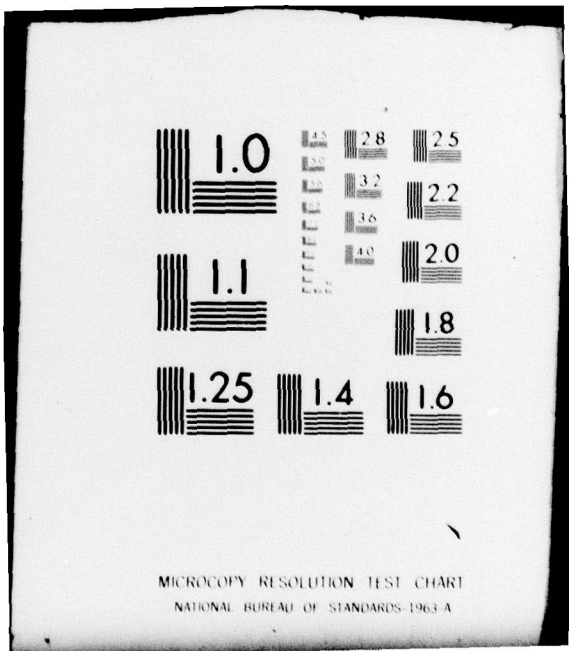
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(12) LEVEL II

(6) TEMPORAL FACTORS IN SONAR TARGET CLASSIFICATION: THEORETICAL AND EXPERIMENTAL ANALYSIS.

(10) John A. / Swets

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(15) ONR CONTRACT NUMBER N00014-76-C-0893

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The objective of this contract was to conduct research on perceptual and decision processes involved in the detection, identification, and scaling of complex visual patterns, with emphasis on temporal aspects of the patterns and processes. During the three and one-quarter years of the project, five BBN technical reports were prepared and distributed, each describing a substantial experiment or set of experiments; all five have been or will be published in the archival literature. A book chapter not

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distributed as a BBN technical report was also prepared. A bibliography of these reports is appended. Also appended is a list of individuals who have been associated with project.

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TO: Chief of Naval Research, Arlington, Virginia 22217

Attention: Engineering Psychology Programs, Code 455,

Drs. M. A. Tolcott and J. J. O'Hare

FROM: Dr. John A. Swets

Bolt Beranek and Newman Inc.,

Cambridge, Massachusetts 02138

SUBJECT: Final report of work completed under the support of Contract N00014-76-C-0893, Work Unit NR 196-145, between Bolt Beranek and Newman Inc. and the Engineering Psychology Programs, Office of Naval Research.

I. This constitutes a final report of work completed under the support of Contract N00014-76-C-0893, Work Unit NR 196-145, between Bolt Beranek and Newman Inc. and the Engineering Psychology Programs, Office of Naval Research. The contract was initiated 1 June 1976 and was terminated 31 August 1979.

II. The objective of this contract was to conduct research on perceptual and decision processes involved in the detection, identification, and scaling of complex visual patterns, with emphasis on temporal aspects of the patterns and processes. During the three and one-quarter years of the project, five BBN technical reports were prepared and distributed, each describing a substantial experiment or set of experiments; all five have been or will be published in the archival literature. A book chapter not distributed as a BBN technical report was also prepared. A bibliography of these reports is appended. Also appended is a list of individuals who have been associated with the project.

III. The research is described here by means of abstracts of the five technical reports and the book chapter. A concluding abstract, prepared for an international congress, summarizes the main part of the work done under the contract.

1. Signal Detection and Identification at Successive Stages of Observation

The relationship of signal identification to signal detection was examined in a series of experiments. The signals were idealized lines and patterns of lines in a spectrographic display. On each trial, progressively more of the complete spectrogram was exposed in successive observation intervals and the observer made both detection and identification responses after each interval that were based on the accumulating evidence. One model employed conceives of detection and identification as proceeding together over time as parts of a unified process. A second model employed shows how the joint detection-and-identification ROC -- a Relative Operating Characteristic that relates the joint probability of correct detection and correct identification to the probability of a false detection -- may be predicted from the simple detection ROC. Both models were supported by the data.

(Technical Report 3535; published in Perception & Psychophysics, 1978, 23(4), 275-289.)

2. Identification and Scaling of Complex Visual Patterns

Experiments were conducted to examine the detection and identification of complex visual patterns, representing various underwater sounds, in terms of stimulus dimensions indicated by a psychological scaling analysis of similarity judgments. Psychological dimensions differed somewhat between naive and experienced observers, and between visual and auditory representations, but high correlations with physical dimensions were found in all cases. A second objective of the study was to relate identification to detection, over successive stages of relatively long signals. The ROC analysis developed for detection of signals in random noise was applied to discrimination of wanted and unwanted signals. The analysis of stimulus dimensions enabled qualitative predictions of the relative levels of detection and identification for different sets of wanted and unwanted signals. The "joint" ROC, based on the probability of correct detection and identification, provided quantitative benchmarks for these predictions.

(Technical Report 3536; combined with Technical Report 3719 for publication as "On the prediction of confusion matrices from similarity judgments," Perception & Psychophysics, 1979, 26(1), 1-19.)

3. On The Prediction of Confusion Matrices from Similarity Judgments

This study of human identification of complex visual stimuli is a step toward an integrated description of the perceptual process whereby stimuli are represented psychologically and the decision process that makes use of this stimulus representation in selecting an identification response. A multidimensional scaling procedure was applied to judgments of stimulus similarity to derive the dimensions of a perceptual space and the relative loci of stimuli in that space, and a probabilistic decision model based on weighted interstimulus distances was developed to predict the confusion matrices in various identification tasks. The high accuracy of the predictions supplies a strong validation of the use of multidimensional scaling procedures to reveal perceptual structure, in demonstrating the ability of that structure to acccount for behavior in an independent task. From the other point of view, the empirical success of this approach suggests a relatively simple and practical means of predicting, and possibly enhancing, identification performance for a given ensemble of visual or auditory stimuli.

(Technical Report 3719; published in Perception & Psychophysics, 1979, 26(1), 1-19.)

4. The Observer's Use of Perceptual Dimensions in Signal Identification

We examine a model of the process of stimulus identification, which assumes that complex visual or auditory stimuli are represented as vectors in a multidimensional perceptual space, and which postulates a simple probabilistic decision process based on the geometric structure of the perceptual space. We present evidence from several conditions of an identification task that human observers engage in a continuing, dynamic process in which dimension salience weights are tuned to optimize identification performance. In addition, we verify the reliability of the INDSCAL multidimensional scaling procedure in deriving the geometric structure of the observers' perceptual space for the set of visual spectrograms used in our identification tasks. We also present evidence supporting an assumption of dimensional decomposability made in the decision process. Finally, we observe that the model is successful in accounting

for approximately 90 percent of the variance in individual confusion matrices, averaged over 18 observers x conditions.

(Technical Report 3930; to appear in Attention and Performance VIII, R. S. Nickerson (ed.) Hillsdale, N. J.: Lawrence Erlbaum Associates, in press.)

5. Identification of Confusible Curvilinear Shapes: Prediction of Individual Confusion Matrices

Identification confusion matrices were obtained from three observers for a set of nine closed, curvilinear shapes. These stimuli, biological in appearance, varied along two nonverbalizable physical dimensions related to the angles of rotation of two of six underlying component forms. Two perceptual dimensions, each linearly related to one of the two physical dimensions, were derived from multidimensional scaling of pair-wise similarity judgments. Using this derived perceptual space and a probabilistic decision model, we were able to account for 95 percent of the variance in individual observer's confusion matrices.

(To appear as Technical Report 4196; to be submitted to Perception & Psychophysics.)

6. Perceptual Spaces Revealed by Multidimensional Scaling Procedures

The development of multidimensional scaling (MDS) procedures in recent years has allowed us to pursue the concept that a complex auditory or visual stimulus can be represented psychologically as a point in a multidimensional perceptual space. In this paper we review the literature which has applied MDS procedures to similarity judgments and to identification confusion matrices to obtain information both about the set of dimensions underlying perception of a set of complex stimuli in the multidimensional space. We also raise the question, what should we require of a multidimensional representation to consider it valid? We suggest one criterion -- prediction of independent data -- and present a model and two sets of data which illustrate the point.

(To appear in "Auditory and Visual Pattern Recognition, D. J. Getty and J. H. Howard, Jr. (eds.) Hillsdale, N. J.: Lawrence Erlbaum Associates, in press.)

7. Perceptual Dimensions: Similarity and Identification

We describe a view of stimulus identification that assumes (1) that complex visual or auditory stimuli are represented perceptually as vectors in a multidimensional Euclidean space, and (2) that the probabilities of identification responses are determined by relative interstimulus distances in the perceptual space. In practice, we derive the dimensions of the perceptual space, and the loci of the stimuli within the space, from application of a multidimensional scaling procedure to pairwise judgments of stimulus similarity. Based on the derived interstimulus distances, we then predict the identification confusion matrix for individual observers by means of a probabiliistic decision model. In a series of three experiments, the model has accounted for an average of more than 90 percent of the observed capability in 33 individual confusion matrices.

Three different sets of complex visual stimuli have been used: (1) a set of 27 synthesized two-formant spectrograms, suggestive of speech spectrograms, which varied along three physical dimensions, (2) a set of 8 spectrograms of real, underwater sounds, and (3) a set of 9 shapes, organic in appearance, that varied along two nonverbalizable physical dimensions. In each case, we derived a perceptual space that could be directly related either to the manipulated physical dimensions (sets 1 and 3) or to physical measures derived from an analysis of the signals (set 2).

Our decision model assumes that perceptual dimensions are not necessarily weighted equally in determining interstimulus distance, and that the relative magnitudes of these dimension salience weights may differ across observers. Furthermore, we suggest that these weights may be adaptively tuned by an observer in order to optimize identification performance, the criterion depending upon both the task and the stimulus set. In an experiment in which observers identified a subset of four "signals," among a set of eight stimuli, with a different subset of four defined as signals in each of 3 conditions, we observed that the patterns of dimension salience weights varied across conditions. Moreover, each observed pattern of weights was generally in agreement with the theoretical pattern of weights that would maximize the probability of correct identification. We have also demonstrated the dynamic

properties of the tuning process in another experiment in which the relative usefulness of a particular dimension was drastically reduced from the first condition of the experiment to the second. Analyzing successive blocks of trials within the second condition, we observed the pattern of dimension weights to change gradually for several observers, from near optimum for the first condition to near optimum for the second.

The use of multidimensional scaling procedures to reveal perceptual structure receives substantial validation from our results, in demonstrating the ability of that structure to account for identification performance in an independent task. At the same time, we gain confidence in the decision model, in demonstrating its predictive accuracy based on an independently derived perceptual space. Finally, this approach suggests a relatively simple and practical means of predicting, and possibly enhancing, identification performance for a given set of visual or auditory stimuli.

(This abstract will appear in the Proceedings of the XXIInd International Congress of Psychology, Leipzig, 1980.)

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